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(54) Gas delivery metering tube

(57) A gas delivery tube is provided. The gas delivery tube includes a plurality of axially aligned nested tubes wherein the innermost tube receives a gas and establishes uniform backing pressure over the length of the innermost tube and an outermost tube provides uniform flow distribution of the gases out through the gas delivery tube.

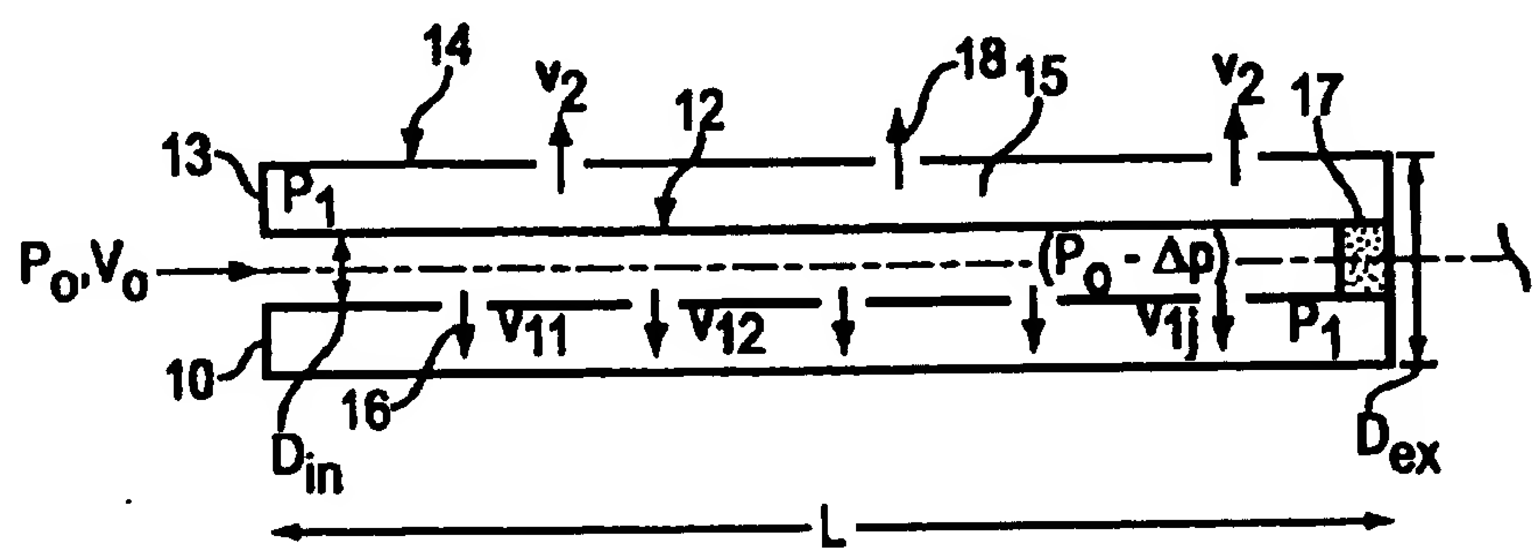

FIG. 5

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Description

[0001] This patent application is related to, and claims priority from, U.S. provisional patent application Serial No. 60/135,358 filed May 21, 1999,which is hereby incorporated by reference.

[0002] This invention relates generally to a gas delivery metering tube for the delivery of gases. More particularly, the invention relates to nested axially aligned or co-axial gas delivery metering tubes that promote substantially uniform distribution of gases.

[0003] The delivery of gases is an important aspect in a great variety of industries. For example, in the field of semiconductor processing or manufacturing, the delivery of gases plays a critical role. One type of semiconductor processing is chemical vapor deposition. Chemical vapor deposition occurs when a stable compound is formed by a thermal reaction or decomposition of certain gaseous chemicals and such compounds are deposited on a surface of a substrate. Chemical vapor deposition systems come in many forms. One apparatus for such a process comprises a conveyorized atmospheric pressure CVD (APCVD) system which is described in U.S. Patent 4,834,020 and is owned by assignee, and is incorporated herein by reference. Other types of CVD apparatus may be used, such as plasma-enhanced CVD (PECVD) systems, and low pressure CVD (LPCVD) systems.

[0004] Important components of a semiconductor processing system include a deposition chamber where deposition occurs, and the injector utilized for delivering gaseous chemicals to the surface of the substrate in the deposition chamber. The gases must be distributed over the substrate, so that the gases react and deposit an acceptable film at the surface of the substrate. The deposition chamber must be carefully designed to provide a controlled environment in which deposition can take place. For example, the chamber must provide gas confinement, but reduce recirculation of the gases which can cause pre reaction of the gases and the deposition of a non-uniform film. The chamber must provide exhaust means for the elimination of excess reactants and reaction by-products, yet not disrupt the flow of gases to the substrate for reaction. Moreover, the temperature of the chamber and its components must be carefully controlled to avoid condensation of reactant gases, minimize accumulation of byproduct dust, and enable cleaning of the system. Additionally, the deposition chamber should preferably maintain mechanical integrity (such as tolerances) throughout its operation. All of these factors must be carefully balanced to provide a proper environment for deposition.

[0005] A function of the injector in such a deposition chamber is to distribute the gases to a desired location in a controlled manner. Controlled distribution of the gases maximizes the chance of efficient, homogeneous gas phase reactions to produce the right kind of chemical species that will result in a high quality film on the substrate. Controlled gas distribution is needed to make sure the entire film is of a uniform composition. reaction of the gases, in part by minimizing pre-mixing and prior reaction of the gases. A complete reaction provides a greater opportunity for a good quality film. If the gas flow is uncontrolled, the chemical reaction will not be optimal and the result will likely be a film which is not of uniform composition. When the film is not of uniform composition, proper functioning of the semiconductor is impaired. Thus, it is important that an injector design facilitates the desired flow of the gases in a controlled manner.

[0006] Gases may be distributed in other areas of the chamber and/or by components in addition to the injector. For example, inert gases may be conveyed to the chamber to separate and/or direct deposition gases in a desired manner. Inert and other gases may be delivered to the chamber to function as dilution and carrier gases. One such example of the use of gases in such a manner is found in co-pending US patent application Serial Number 09/185,180, the entire disclosure of which is hereby incorporated by reference.

[0007] In the field of semiconductor fabrications, with device geometries shrinking to <0.2 micrometers comes the increasing demand for film deposition thickness nonuniformities of <2% range. The prior art for linear gas distribution systems has not been entirely successful in meeting these greater requirements. The simplest prior art design is a single tube with a distribution of holes or orifices along its surface as shown in Fig. 1, having a tube length of L and a diameter of D, with multiple orifices having diameter d. Gas is introduced at one end of the tube at a pressure P_o and an initial velocity V_o. In this design, uniformity will typically be dependent on pressure. At each orifice, pressure and flow are reduced by some amount. Assuming the orifice sizes are small compared to the tube diameter D, and the supply pressure is adequately large, then the pressure and flow reduction per orifice are small compared to P_o and V_o. Reduction in velocity along the tube is typically accompanied by an increase in pressure, except for small gas flows. At some distance far from the gas supply, the pressure in the tube P_o will have dropped (as expressed by: $P_o - \Delta p$). With a single metering tube having orifices of the same diameter and equally spaced, uniform gas flow is not achieved. A particular shortcoming of the single tube prior art is the difficulty of providing good uniformity over increasing lengths needed to accommodate larger substrate sizes or diameters. For certain pressures, a given dimensional relationship between D, d, and L will result in somewhat uniform velocity vectors (v_i) and uniform gas flow by either redistributing these orifices of same given diameter or by varying the diameters of equally spaced holes. However, this distribution of orifices will result in optimum flow for a narrow range of operating conditions, if not just one particular operating condition. Moreover, such prior art design typically produce films having a high thickness nonuniformity of about 5 to 10%, depending upon the gas flow and pressure. Additionally, at low gas flows and low pressures, a higher flow of gas will emerge from the end nearest the supply as illustrated in Fig. 2. In other words, if P_o is a relatively low value, the overall pressure in the

tube drops more quickly as a function of the distance from the gas supply. The overall flow uniformity in this case will be very poor. In addition, gas flow from such tubes will tend toward increased directionality (also referred to as "jetting") as the supply flow and pressure increase. The gas flow out of the tube is nonuniform and exhibits linear decrement across its length as shown in Fig. 3a. Alternatively, gas may be introduced at each end of the tube as shown in Fig. 3b. In both cases the gas flow is not distributed uniformly which results in non-uniform deposition across the wafer.

[0008] An alternative prior art approach is the use of a single tube of porous material. Again, gas is introduced at one end of the tube. With this approach the "jetting" issue that accompanies a tube with holes is minimized. The porosity of the material will typically determine the achievable backing pressure within the tube, and hence also the overall uniformity along the length of the tube. For example, a screen mesh may be considered a porous material. For best uniformity, the mesh must offer good resistance to gas flow to maintain good backing pressure along the full length of the tube. Typically resistance to flow depends on the overall open area to tube surface area. Mesh openings are typically of the order of the thickness of the material or larger (>0.005 inches). A second example is a porous ceramic having particle spacings on the order of micrometers (such materials are used often in filtration devices) and thicknesses on the order of millimeters. Such materials could offer resistance to gas flow to enable build up of uniform backing pressure, and good uniformity of delivered gas along the full length of the delivery line.

[0009] Though porous ceramic tubes can provide good uniformity of gas delivery, the material itself is quite fragile, and seals to the gas supply lines that can also withstand a wide range of temperatures are difficult to make.

[0010] A third alternative is to taper the tube diameter as a function of distance from the supply so that the fluid velocity is kept constant while the mass rate of flow decreases. The main drawback to this approach is that a design optimized for uniform flow at one flow rate will not work correctly at another flow rate.

[0011] The biggest weakness of the prior art using single perforated or porous tubes is that they show relatively high sensitivity to changes in pressure, resulting in nonuniform flow as a function of position along the length of the delivery tube. Further, as shown in Fig. 4, non-uniform flow is a strong function of the gas flowrate, and as different applications and process conditions call for different gas flow rates, it becomes increasingly complicated to design and develop processes that provide uniform film deposition. The plots illustrated in Figure 4 represent a range of gas flow conditions and geometries typical of CVD applications, having Reynolds numbers $100<R_e<2000$. Moreover, as wafer diameters increase, the film non-uniformities are often exacerbated with increasing length of the gas delivery tube.

[0012] Changes in pressure may be imposed deliberately by a user, but often times occur due to fluctuations in the facilities gas delivery system to the CVD system. Thus, with the prior art, changes in gas pressure will influence the uniformity of gas delivery within the injector and/or deposition chamber, which then influences the resulting film uniformity or composition on the substrates. In other words, with prior art systems the gas delivery apparatus may be useful for only one operating condition. Accordingly, it is desirable to provide a gas delivery system that promotes substantially uniform flow and/or distribution of gases, particularly along a length which is impervious to fluctuations in the delivery system, and over a wide operational range of gas flows.

[0013] It is an object of the present invention to provide an improved gas delivery metering tube for delivery of gases, and more particularly to provide substantially uniform gas delivery along the length of a gas delivery tube having gas supplied at one end. These and other objects are achieved by a gas delivery metering tube having a combination of nested, axially aligned or co-axial metering tubes wherein an innermost tube receives a gas and establishes substantially uniform backing pressure over the length of the innermost tube and an outermost tube provides uniform flow distribution of the gases out through the gas delivery tube. In another aspect of the invention, a gas delivery metering tube is provided in combination with at least one injector assembly having at least one port for receiving the gas delivery metering tube. In yet another aspect of the invention, a gas delivery metering tube is provided in combination with a shield assembly having at least one plenum for receiving the gas delivery metering tube. The gas delivery metering tube is particularly suitable for use in semiconductor applications.

[0014] Other objects and advantages of the invention become apparent upon reading of the detailed description of the invention and the appended claims provided below, and upon reference to the drawings, provided by way of example, in which:

Figure 1 is a cross-sectional view of gas flows in a single tube used in the prior art.
Figure 2 is a cross-sectional view of gas flows in a single tube used in the prior art when the pressure is low.
Figure 3a and 3b are schematic representations of the gas flow non-uniformities of the prior art.
Figure 4 is a graph illustrating the gas flow distribution along the length of various types of tubes (prior art).
Figure 5 is a cross-sectional view of the gas delivery tube of the present invention.
Figures 6a and 6b are cross-sectional end views of the gas delivery tube according to two embodiments of the present invention.
Figure 7 is a cross sectional view of one example of a CVD deposition chamber showing a protective shield and an injector which may employ the gas delivery tube of the present invention.
Figure 8 is a cross sectional view of one example of an injector which may employ the gas delivery tube of the

present invention.

[0015] Of particular advantage, the present invention provides a gas distribution tube that meters the gas distribution along a length, in particular the length of the tube, and makes the resulting gas distribution from the tube less sensitive to pressure changes over a wide range of operating conditions or gas flow ranges, and addresses the shortcomings of the prior art. The present invention consists of a gas delivery tube having a tube assembly of two or more nested, axially aligned or coaxial tubes with the innermost tube preferably attached to a gas supply, and with both the inner and outer tubes having one or more arrays of orifices distributed along the lengths of the innermost and outermost tubes. For purposes of discussion, a gas delivery tube 10 comprised of two axially aligned, nested tubes having circular cross section shall be discussed, however other numbers of tubes can be used such as three nested or more coaxial tubes. The length of gas delivery tube to be used to process semiconductor substrates is typically several centimeters longer than the width or diameter of the substrate.

[0016] One embodiment of the invention is shown with reference to Figures 5 and 6a. Figure 5 is a schematic drawing of a gas delivery tube 10 comprised of a two tube assembly having coaxial inner 12 and outer 14 tubes separated by an annular space 15. Each tube has two ends. The inner tube 12 has one end 13 attached to the gas supply and the other end 17 is capped. One or more arrays of orifices 16 are distributed along the substantial length of the inner tube 12, and are positioned and sized to establish a uniform backing pressure along the full length of the inner tube 12, and still provide sufficient gas flow out of the inner tube 12 into the annular space 15. The outer tube 14 contains an array of orifices 18 distributed along its substantial length. The one or more arrays of orifices 18 are positioned and sized to maintain a uniform backing pressure within the annular space, and to provide uniform gas flow out of the outer tube 14 and into the area adjacent the outer tube 14. Preferably, the outer tube 14 is capped at both ends; however, in an alternative embodiment the outer tube may also receive a gas supply. Preferably, the line of inner orifices 16 are rotationally offset 180 degrees from the line array of outer orifices 18 as shown in Figure 5 and 6a. However, any rotational alignment and liner alignment between these arrays can be used. The preferred embodiment aligns the inner array of orifices 180° from the outer array of orifices.

[0017] While the gas delivery tube 10 has been described having two axially aligned nested tubes, additional tubes may be used. For example, the gas delivery tube 10 may be comprised of three, or more, coaxial tubes. Through the use of two or more nested coaxial tubes, the inventive apparatus reduces the sensitivity to pressure effects over a wide flow range by first establishing uniform backing pressure along the length of the inner tube, and then maintaining and transferring that uniformity and constancy of pressure to the annular space between the two tubes over the full length of the tube assembly 10. The resulting gas outflow from the outer tube can thus be quite uniform. The present invention thus effectively separates the establishment of pressure and flow over the length of the tube assembly into two steps.

[0018] As discussed above, the prior art having a single tube with an array of orifices and supplied by gas at one end requires that the gas backing pressure be equivalent over its full length to provide uniform flow out of the array of orifices. At low flow conditions, the backing pressure may fall too low, and flows from orifices furthest from the supply may drop resulting in nonuniform distribution over the length of the tube. In contrast, according to the present invention, the inner tube 12 of the present invention is sized in diameter and the array of orifices 16 to establish uniform backing pressure along its full length In other words, the relationship between the diameter of the tube and the diameter of the orifices is important. The orifices 16 are distributed along the substantial length, and preferably the full length, of the inner tube 12 and are sized and numbered to ensure sufficient resistance to gas flow outward from the inner tube to build backing pressure within the whole inner tube's length. Gas flow from the inner tube is evenly distributed along its length, and feeds the annular space between the inner and outer tubes.

[0019] In Mokhtari et al. ("*Flow Uniformity and Pressure Variation in Multi-Outlet Flow Distribution Pipes,*" Advances in Analytical, Experimental and Computational Technologies in Fluids, Structures, Transients and Natural hazards, ASME, PVP - Volume 355, page 113, 1997) the general relationships among the inner diameter of the inner tube 12 (D_{in}), tube length L, and orifice size (d_{in}) for establishing uniform flow along a single tube, are discussed. Further, in Acrivos et al. ("*Flow Distribution in Manifolds,*" Chemical Engineering Science, Vol. 10, pages 112 to 124, Pergamon Press 1959) requires that $L/D_{in} < 70$ while Mokhtari suggests by example that $L/D_{in} > 50$. In addition, Mokhtari et al show that $D_{in}/d_{in} \approx 10$ or more should expect to provide good flow uniformity over the full length of the tube. Acrivos suggests that the ratio of total orifice area ($N\pi d_{in}^2/4$) to area of the manifold ($\pi D_{in}^2/4$) should not exceed unity.

[0020] The prior art thus provide a set of rules to establish relatively stable backing pressure in a single tube. Specifically, the following relationships are shown: $L/D<70$, $D/d \rightarrow >10$, and $Na_{port}/A_{tube} \approx 1$, where N is the number of orifices in the tube, and a_{port} is the cross sectional area of each of these orifices. This prior art is limited to a single tube arrangement, however, and as discussed above such single tube arrangements are limited in their performance and do not provide satisfactory film uniformity.

[0021] The inventors have discovered that maintaining the prior art requirements for the inner tube 12 establishes relatively stable backing pressure ($P_0 - \Delta p$) within the inner tube 12. Further, the inventors have discovered that maintaining substantially constant gas flow from the orifices 16 of the inner tube feeds into the annular space 15 between